

Spectrum and Orbit Conservation As a Factor In Future Mobile Satellite System Design

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ABSTRACT

Access to the radio spectrum and geostationary orbit is essential to current and future mobile satellite systems. This access is difficult to obtain for current systems, and may be even more so for larger future systems. In this environment satellite systems that minimize the amount of spectrum-orbit resource required to meet a given traffic requirement are essential. Several spectrum-conservation techniques are discussed in this paper, some of which are complementary to designing the system at minimum cost, others less so. All may need to be implemented to the limits of technological feasibility if network growth is not to be constrained because of the lack of available spectrum-orbit resource.

1. INTRODUCTION

Spectrum and orbit conservation in the context of the mobile satellite service is the business of ensuring that the frequency bands and the geostationary orbit (GSO) available to mobile satellite system operators are used effectively. Spectrum-orbit conservation can perhaps be considered within the broader theme of environment conservation, but with a difference: while environmental problems such as water and air pollution, deforestation, etc. degrade the environment in a tangible way, the radio spectrum and GSO is not "destroyed" in the same direct way; it is in theory completely reusable at any future time. But when we introduce the telecommunication engineer's ongoing problem of being a slave to his own history, next year's

and next decade's systems having to be compatible with those of the last decade, it is quite possible to degrade the spectrum-orbit "environment" over a long period of time, with system designs having short-term economic advantages but using larger than necessary amounts of the spectrum-orbit resource. It is in the mobile-satellite system operator's long-term interests to use good spectrum and orbit conservation techniques, whether they be to ensure coordination of his present system or to ensure spectrum is available for his follow-on system.

This paper attempts to find ways of balancing the objectives of designing mobile satellite systems that are both cost-effective and that make good utilization of the available spectrum-orbit resource. These are in some instances complementary objectives, and in other cases divergent. In the latter case they are likely to be followed only through the process of setting radio regulations at the international (ITU) level, the national level (in Canada through policies and regulations set by the Department of Communications), and by coordination agreements among mobile satellite system operators through the Article 11 (Radio Regulations) process.

In the 1 to 3 GHz band, where there are a large number of users and potential users, and where many systems and services are at an early stage in their development, it is particularly important to weave good spectrum and orbit conservation techniques into the design of systems. Another reason for paying particular attention to such techniques at this

time is that WARC-92 will likely set the basic international radio regulations for the mobile satellite service in the 1-3 GHz band for the next decade at least.

Spectrum-orbit conservation can perhaps be considered from two different aspects: sharing the resource between the networks of a given service, the mobile-satellite service in this case, and the sharing of the resource between the mobile-satellite service and other radio services. The latter may or may not be possible, but we must know whether it is possible by the time we go to WARC-92. The first question will be considered in section 2, the second in section 3.

2. SPECTRUM-ORBIT SHARING AMONG MOBILE SATELLITE SYSTEMS

Unless or until spectrum-orbit conservation is a basic design objective of the satellite-system designer, his job is essentially to design the system with the required capacity and required signal quality at the minimum possible cost. Perhaps the first step in examining spectrum-orbit sharing among mobile-satellite systems is to look at that design problem from the perspective of the system noise budget. The overall link carrier-to-noise ratio (c/n) is given by the equation

$$\frac{c}{n} = \left\{ \left(\frac{c}{n} \right)_u^{-1} + \left(\frac{c}{n} \right)_d^{-1} \right\}^{-1} \quad (1)$$

where $(c/n)_u$ and $(c/n)_d$ are the uplink and downlink carrier to noise ratios respectively. The uplink ratio $(c/n)_u$ can be specified by the equation

$$\frac{c}{n}_u = \frac{p \cdot g(\phi) \cdot l \cdot f \cdot h(\phi)}{kTB} \quad (2)$$

where p is the earth-terminal transmitted power,
 $g(\phi)$ is the earth terminal antenna gain at an angle ϕ degrees off boresight,
 l is the uplink free-space loss,
 f is the fading loss that must be included in the design,

$h(\phi)$ is the gain of the spacecraft antenna at an angle ϕ degrees off boresight,
 k is Boltzman's constant,
 T is the uplink effective noise temperature, and
 B is the uplink noise bandwidth, approximately equal to the signal necessary bandwidth.

A similar equation exists for $(c/n)_d$ to go into equation (1). The mobile satellite system designer's task is to balance the choice of p , g , h , T , f , and B to minimize the system cost subject to a specified (c/n) , taking into account such factors as satellite weight budget, number of earth terminals, traffic growth over the systems design life, etc.

2.1 One Spectrum-Orbit Conservation Choice: Signal Bandwidth

The most obvious interface between the system designer and the frequency manager is the choice of the bandwidth parameter B of Eqn (2). If n channels are to be accommodated in a given area, the required bandwidth of the system is nB ; if the total available bandwidth is fixed, n can only be increased by decreasing B . However, in decreasing B by choosing a different type of modulation, the system designer is confronted by a tradeoff between bandwidth and power to transmit a given signal of given post-detection quality (S/N) . Power is costly, especially on the spacecraft, and so one must speak already of the "cost" or "value" of spectrum conservation. Further, decreasing B at the expense of requiring a higher carrier to interference ratio (c/i) may or may not be a good choice from an overall spectrum-orbit conservation perspective, because higher (c/i) values mean larger satellite spacings, and possibly reduced potential for interservice sharing.

2.2 A Second Spectrum-Orbit Conservation Measure: Spacecraft Antenna Discrimination

To understand a series of spectrum-orbit conservation measures

one should look at the carrier-to-interference equations that quantify the interference mechanism between two satellites. These are similar to the (c/n) equations (1) and (2) above. The uplink (c/i)_u carrier-to-interference equation for two networks using the same frequency in the same direction is

$$\left(\frac{c}{i}\right)_u = \left(\frac{p}{p'}\right) \left(\frac{g(o)}{g(\Theta)}\right) \cdot \left(\frac{1}{1'}\right) \left(\frac{f}{f'}\right) \left(\frac{h(o)}{h(\phi)}\right) \quad (3)$$

where the superscript (') refers to a parameter of the interfering network, Θ is the separation angle on the GSO between the interfered-width and the interfering satellite, and (ϕ) is the angle off boresight of the interfering Earth-station as seen from the interfered-width satellite location.

The spacecraft antenna discrimination $\{h(o)/h(\phi)\}$ may be enough to provide the necessary (c/i)_u, with or without assistance from other factors of Eqn (3). A particular case of Eqn (3) is with $\Theta = 0$, i.e. the interfering and interfered-with networks being on the same spacecraft. This is the situation with multi-beamed spacecraft with enough isolation between beams to permit frequency reuse. This frequency-conservation measure may be complementary to the objective of minimizing overall system cost if larger antenna gain $h(o)$ and lower downlink power p in the downlink counterpart to Eqn (2) results in a lower spacecraft cost to provide a given EIRP. However, the provision of steep antenna-gain rolloff characteristics and high values of $\{h(o)/h(\phi)\}$ may require satellite costs greater than that expended simply to provide the required satellite EIRP at minimum cost. Thus again there is a need to quantify a "value" or "cost" to spectrum conservation, in this case through frequency reuse.

2.3 A Third Spectrum-Orbit Conservation Measure: Earth Terminal Antenna Discrimination

Another factor in Equation (3) is the Earth terminal antenna discrimination factor $\{g(o)/g(\Theta)\}$. It may be possible to design an antenna with enough earth-terminal

antenna discrimination to permit frequency reuse of the GSO from another satellite away. Given that the mobile terminal must operate while moving, some combination of mechanical and/or electronic (phased array) steering would be required. This technique is at least partially complementary to the objective of minimum-cost design in that a higher gain antenna, and therefore an antenna with greater discrimination, will permit lower satellite transmit powers and consequently lower satellite weight and cost.

2.4 A Fourth Spectrum-Orbit Conservation Measure: Network Homogeneity

If Earth terminal antennas can be designed with enough discrimination that frequency reuse at orbit separations say 30° to 60°, then it becomes important to minimize the inhomogeneity between the networks so that this angle can be minimized. This inhomogeneity is expressed in Eqn (3) by the parameter (p/p'). If two networks have significantly different transmitted power levels, for one or another reason, then the necessary separation angle to protect the low-power network is greater than that necessary to protect the high-power network. However, the angle between them has to be large enough to protect both, and so must be the larger of the two. To minimize this angle, the two networks should be designed with $p_1 \simeq p_2$. There may be variations from this when this factor is combined with others mentioned above, but the trend should be to avoid large differences between p_1 and p_2 . This hasn't been considered seriously to date because Earth terminal antenna discriminations are not yet large enough to allow frequency sharing at less than "over-the-horizon" separations. Hopefully, this will change, and when it does p_1/p_2 inhomogeneities will be a significant factor in spectrum-orbit utilization.

3. SPECTRUM SHARING BETWEEN NETWORKS OF DIFFERENT SERVICES

There are in theory a large number of possibilities that might be

considered here, but two are particularly attractive:

- i) sharing between different mobile-satellite services, i.e. the aeronautical mobile-satellite service (AMSS), the land mobile satellite service (LMSS), and the maritime mobile-satellite service (MMSS); and
- ii) sharing between these satellite services and the terrestrial fixed and mobile services.

3.1 Spectrum Sharing Between Mobile Satellite Services

In the ITU Radio Regulations the frequency bands 1530 to 1559 MHz and 1626.5 to 1660.5 MHz are divided into a number of sub-bands allocated to various combinations of AMSS, LMSS, and MMSS on a primary and secondary basis. In contrast, according to Canadian spectrum policy document SP 1530, these bands are allocated to the composite Mobile-Satellite Service (MSS) with two exceptions:

- i) the bands 1545-1548 MHz and 1646.5-1649.5 MHz are allocated to the aeronautical mobile satellite service exclusively, (and this excludes air public correspondence), to provide a firm base for the development and implementation of air-traffic-control systems by satellite; and
- ii) aeronautical mobile satellite traffic, (excluding air public correspondence) must be provided a means of real-time priority or interrupt in the higher bands 1548-1559 MHz and 1649.5-1660.5 MHz, in recognition of the fact that ATC traffic needs very fast response from the telecommunications network that it uses.

There are three reasons for taking this approach that are related to the objective of conserving or making better utilization of the radio spectrum and the GSO:

- i) in a relatively new service (or services) such as the MSS, it is not obvious that the division of capacity requirements should be

made in a particular way. The attendant requirements of the AMSS, LMSS, and MMSS may evolve at different rates and to different extents from that foreseen in dividing the band between the three services. The more generic approach allows the evolution of system development to accommodate the different services as they emerge.

- ii) the requirements for AMSS, LMSS, and MMSS vary in different geographical areas. For instance, there is very little demand for LMSS capacity in mid-Atlantic, and similarly very little demand for MMSS capacity on the Canadian prairie. This becomes important as the systems evolve from the earlier global-beam systems to those using multi spot beams with frequency reuse, discussed in section 2.2.
- iii) the different types of MSS traffic have definite diurnal peaks, and if these peaks differ for the different types of traffic more efficient use of a given block of spectrum can be made by combining the services in a larger composite network. As an example, the trans-Atlantic air travel has definite diurnal patterns in eastern North America, with traffic to North America peaking in early afternoon local time and Europe-bound traffic peaking in the evening.

This combining of mobile-satellite services in a 'generic' system to make more efficient use of the spectrum is complementary to the system designer's objective of designing a minimum-cost system, in that in designing a larger composite system considerable economies of scale in satellite design can be obtained, and perhaps economies of producing larger numbers of similar Earth terminals. As well, it allows the system operator to increase the utilization of his facility by integrating the different types of traffic.

3.2 Sharing Between Mobile-Satellite and Terrestrial Services

WARC-MOB-87 recognized the need to review the ITU allocations to mobile-satellite services in the near future; presumably that will take place at WARC-92. There are, however, no unused frequency bands in the 1 to 3 GHz range of the radio spectrum. Agreement for additional allocation to spectrum for mobile-satellite services would be eased considerably if these services could share on a simultaneous-use basis with terrestrial services such as the fixed and/or the mobile services.

Sharing is not as convenient as an exclusive band, but it may be feasible, particularly in the MSS downlink. In that direction interference is between the transmitting spacecraft and the receiving terrestrial station, and from the associated transmitting terrestrial station and the receiving Earth station. In this sharing arrangement the key may be in using directive Earth-station antennas, seen in section 2.3 as providing spectrum and orbit conservation for a completely different reason. If higher gain directive Earth station antennas can be used this would reduce the required power-flux-density on the ground from the satellite, thereby easing the interference into terrestrial receivers. Moreover, such directive antennas would reduce the interference from transmitting terrestrial stations. Perhaps sharing arrangements in the MSS downlink can be agreed upon.

In the bands used for the MSS Earth-to-space link sharing may be more difficult, because the satellite receiver is subject to interference from the composite of all the terrestrial transmitters in its coverage area. Sharing may be possible with fixed systems, because antennas of fixed systems should not be pointed at the geostationary orbit. However, sharing with transmitting terrestrial mobile systems would be more difficult and may not be possible.

4. SUMMARY

A number of spectrum and orbit conservation techniques involving the design and operation of mobile-satellite systems have been described. Some of these may be considered at WARC-92, others more appropriately considered in the normal activities of the CCIR. But in the final analysis they can only be put into effect if spectrum and orbit conservation is fully integrated into the design and operation of a mobile-satellite system, not put together after the system has been designed and is about to be "coordinated" under Article 11 of the Radio Regulations. The mechanisms are there; some are complementary to minimum-cost design, others less so. But the health of the mobile-satellite industry over the longer time-frame depends on effective available spectrum and orbit conservation techniques being implemented.